



REDESIGN OF FOUR-LEG URBAN INTERSECTION WITH LIGHT RAIL IN A CORRIDOR OF TWO STREETS: CASE STUDY IN ZAGREB

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Abstract

In the Croatian capital Zagreb, due to the spatial expansion and the increasing number of inhabitants and cars, there is a constant need for the reconstruction of existing or the construction of new road infrastructure in accordance with the mandatory regulations and requirements. The lack of uniform national guidelines for the design of urban streets and intersections often leads to different and inconsistent solutions. Increasingly problematic in the street network are poorly designed intersections in urban areas. Great attention should be paid to the geometric design of intersections, as large cities have a complex traffic system due to the high volume of traffic and different road users. In this paper, the existing intersection of Grad Vukovar and Grad Gospić streets in the city of Zagreb with a light rail corridor in both streets was analysed, and two preliminary design variants for the reconstruction of the intersection were proposed to show the design problems and their solution.

Keywords: guidelines; regulations; redesign; urban intersection; light rail

1 Introduction

Signalized four-legged intersections are an indispensable part of the urban street network, and special attention should be paid to their geometric design. As critical parts of the urban street and traffic network, intersections are areas where certain activities take place, be it driving, walking, cycling, or lingering. For this reason, they can be the source of serious conflicts between pedestrians, cyclists, and vehicles if they are not carefully designed, especially when it comes to intersections with light rail in street corridors. According to [1] the efficiency of urban intersections and the quality of urban life are influenced by the position of the intersection in the urban street network, the design of adjacent intersections, and the type of use of surrounding land. The geometric design of urban intersections is usually based on guidelines, and requirements for the design of certain elements may be prescribed in ordinances and city plans. The guidelines [2-4] usually define typical cross-sections (corridors) of carriageways on urban streets with pedestrian and cycle paths, lanes for vehicle traffic and public transport (light rail and busses). They describe the methodology for the design of intersection elements (lane edges, additional lanes for left and right turns, different types of traffic islands) and define different options for guiding pedestrians and cyclists across the intersection. All these guidelines have in common is that they contain no information on the design of intersections with light rail vehicles in the street corridor. According to [5], a major problem is that most accidents with injuries occur at urban intersections. Since human error is the main cause of these accidents, it is good to know how the characteristics of intersections affect the “safety influence area” [5]. Proper organization of all road users at intersec-

tions is important to avoid congestion and is the basis for safe traffic flow. The analysis of traffic simulation at intersections in [6, 7] shows that appropriate channelization measures at intersections can contribute significantly to improving traffic capacity. According to [8], the main factors influencing the safety level of pedestrians were found to be the width of the median, the number of vehicles during the non-green phases for pedestrians, the number of vehicles passing in parallel and the number of vehicles in the crosswalk area.

The lack of national Croatian guidelines for the design of urban intersections often leads to inconsistent geometric design of intersections within the street corridor, which affects operational efficiency and safety. This is particularly evident in the city of Zagreb on Grad Vukovar Street, where, for example, the safety islands for pedestrians and cyclists at intersections are inadequately dimensioned or missing and tram stations are very narrow, and when pedestrians and cyclists cross the intersection, the risk of collision with motor vehicle and light rail traffic increases. For this reason, this paper analysed the design of intersections with light rail in the street corridor at the existing intersection of Grad Vukovar and Grad Gospić streets and proposed two preliminary design variants for the reconstruction of the intersection. The main goal was to show the design problems and their solution and to show what the standard design for urban intersections should look like.

2 Overview of the literature on the design of urban intersections in Zagreb

In the city of Zagreb, the geometric design of intersections is mostly done in accordance with the:

- General urban plan of the city of Zagreb [9]. It covers an area of about 220 km² and divides the basic street network into urban highways (city bypasses), urban avenues, urban main streets, and urban streets. A corridor or an extension of an existing road with a width of at least 80 m must be provided for an urban highway, a width of at least 40 m for an urban avenue, at least 26 m for an urban main street and at least 18 m for an urban street. Cycle lanes and cycle paths can be built and arranged separately from streets as a separate area within the street profile and as part of the roadway marked by traffic signs. If the cycle path or walkway is directly adjacent to the road, there must be a buffer of 0.75 m between them. A buffer is not required if the speed of motor vehicles on the road is limited to 50 km/h. As a rule, it is possible to build light rail lines in an area separate from the carriageway. If it is possible to build light rail line along the carriageway, a 3.0 m wide space must be provided for the light rail tracks. If it is possible to build light rail line on an area separate from the carriageway, a 15.0 m wide space, but at least 9.0 m wide, must be provided.
- Detailed urban development plan [9], usually created for a small area of the city, a neighbourhood or part of a neighbourhood (Fig. 1). It provides in detail the typical street cross-section with the dimensions of the individual design elements within the profile.
- Ordinance on Cycling Infrastructure [10]. According to this, one-way cycle lanes or paths must have a minimum width of 1.0 m and two-way cycle paths must have a minimum width of 2.0 m. Cycle paths in urban areas must be at least 0.5 m from the edge of the carriageway and at least 12 cm above the carriageway level. Cycle lanes and cycle paths at road intersections are positioned closer to the middle of the intersection and their minimum width is 2.0 m.
- Technical regulation to ensure accessibility of buildings for people with disabilities and reduced mobility [11]. It specifies that the refuge islands must have a minimum width of 1.8 m and where the tactiles must be placed.
- German guidelines [3]. It is mainly used for the design of traffic islands, additional lanes for left and right turners, and lane edges.
- Ordinance for Traffic Signs, Signals and Road Equipment [12]. It defines the way signalization and road equipment is placed on roads.

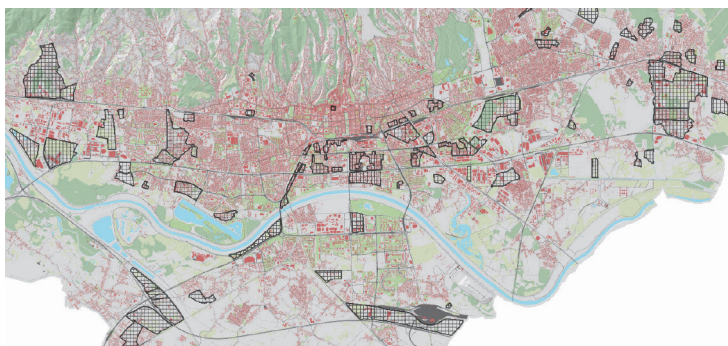


Figure 1 Locations of the Detailed urban development plans for the city of Zagreb [9]

3 Methodology

The research methodology consists of analysis General urban plan and existing intersection, geometric design of all intersection and street design elements (lanes, islands, and carriage-way edges) according to plans, regulations, and guidelines, swept path analysis for the design vehicle, and re-design of elements according to the swept path analysis.

4 Location of the intersection and description

Intersection of Grad Vukovar and Grad Gospić Streets has been analysed (Fig. 2). It is in the eastern part of the city of Zagreb. Grad Vukovar Street is classified as urban avenue and extends from Trešnjevački Square in the west to Grad Gospić Street in the east for a length of about 5.5 km (Fig. 2). At the same time, it crosses the main urban streets and avenues of the city, running in a north-south direction, which gives it great importance in the traffic network of the city. Grad Gospić Street is also classified as urban avenue which stretches from Grad Vukovar Street in the north to Koledovčina Street in the south for a length of about 1.3 km.



Figure 2 Intersection of Grad Vukovar and Grad Gospić Streets (source: Google Maps)

The speed limit on the Grad Vukovar and Grad Gospić streets is 50 km/h. There are two lanes on Grad Vukovar and Grad Gospić streets. There are sidewalks only on the north side of Grad Vukovar Street and on the east side of Grad Gospić Street. There are no cycle paths or cycle lanes on Grad Vukovar Street, while on Grad Gospić Street there are cycle lanes on the sidewalk next to the pedestrian path. At the intersection of Grad Vukovar and Grad Gospić streets, there is a crosswalk marked with horizontal and vertical signals (Figure 2).



Figure 3 Width of street corridors [9]

On the southern side of Grad Vukovar Street, there is a light railway and a tram stop called “Ferenščica”. At the intersection of Grad Vukovar and Grad Gospić streets, the tram line does not run along the streets. Detailed urban development plan [9] for the redesign of this streets and the intersection (Fig. 1) is available, but it is outdated (no longer complies with the latest regulations). Important thing that can be taken from this plan is that the streets will have two carriageways separated by a median with a light rail system. As the further development and urban expansion of Grad Vukovar Street to the east and Grad Gospić Street to the north is expected, it is necessary to redesign the intersection and adapt it to the current and planned needs. In the General urban plan [9] for the redesign and reconstruction of the streets and the intersection in Grad Vukovar Street, a corridor with a width of 55 meters and 36.5-39 meters in Grad Gospić Street is envisaged (Fig. 3).

5 Research results

Two variants of the four-legged intersection were geometrically designed at the selected location [13]. First, the cross-sectional elements on streets were determined for the design speed of 60 km/h (Fig. 4), followed by the geometric design of the intersection (Figs. 5, 6). In both variants of Grad Vukovar Street, on the east and west legs, there are dual carriageways with six lanes, each 3.25 m wide, separated by a 13.25 m wide median. Within the median, there is a 6.0 m wide strip for the tram tracks, a 4.25 m wide section for the tram station and two 1.0 and 2.0 m wide sections with green areas. The prescribed directions of travel are indicated by arrows on the lanes, and the lanes are intended for straight-ahead traffic and for left and right turns. Additional lanes for left and right turners have been created so that vehicles travelling from east to west and vice versa travel in a straight line.

In both variants of Grad Gospić Street, on the north and south legs, there are (Fig. 5, 6) also dual carriageways but with five and six lanes, each 3.25 m wide, separated by a median with (12.0 m wide, with tram station) or without (8.75 m wide) a tram tracks. Directions of travel are marked by arrows on the lanes, and additional lanes have been created for left and right turners. On the south leg there is no separate lane for right-turning vehicles; it is combined with the straight-ahead lane. Vehicles travelling from north to south and vice versa move in an arc, as the street axis is an arc with a radius of 245 metres. Minimum radius of tram track in left or right turn is 22 m.

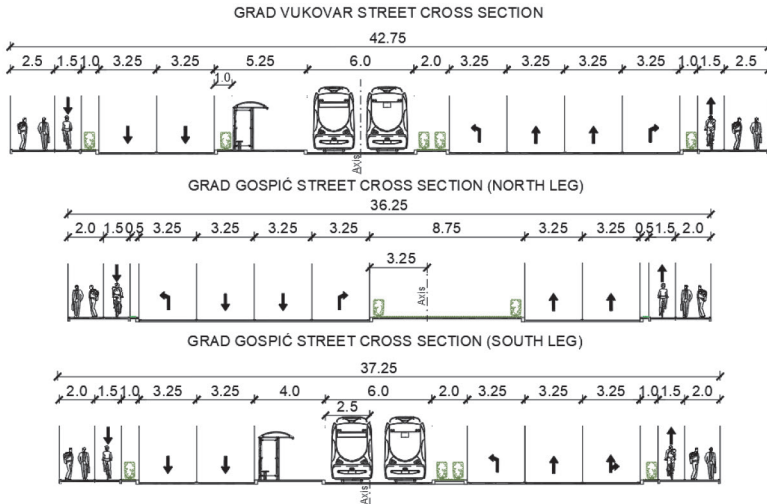


Figure 4 Cross sections of Grad Vukovar and Grad Gospić Street

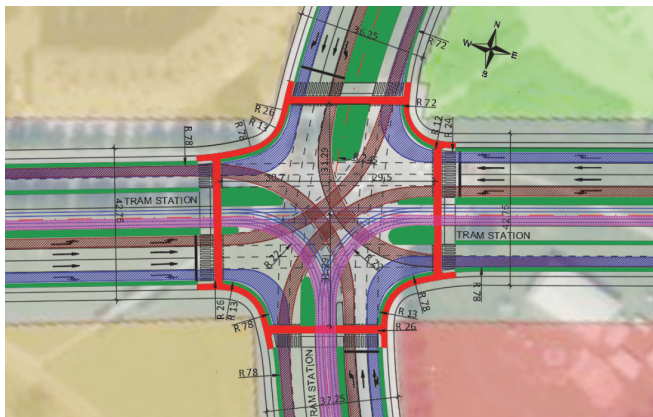


Figure 5 Variant 1 of the intersection

When designing the geometry of the intersection, particular care was taken to direct pedestrian and bicycle traffic in such a way as to minimise the impact of car traffic. Pedestrian and bicycle traffic (one-way traffic) is guided along the sidewalks on the outer edge of Grad Vukovar Street and Grad Gospić Street, which are separated from the carriageway by a 0.5 or 1.0 m wide green strip. Continuous crosswalks are defined with a width of 3.0 m and bicycle crossings with a width of 2.0 m, while the total width with protective strips is 6.5 m, which is in accordance with the regulations [10]. The minimum width of the refuge island in the median to protect pedestrians and bicyclists is 2.0 m. Pedestrians and cyclists are protected by refuge islands when crossing the median so that they are not exposed to the movements of turning vehicles and trams. For this reason, the crosswalks are about 30.0 m from the centre of the intersection. The difference between the two variants (Figs. 5, 6) is that the second variant has triangular islands on the southern leg (there is not enough space for islands on the northern leg due to the nearby buildings), which serve to separate right-turning traffic (bypass), accommodate pedestrians and cyclists, and shorten the path of pedestrians and cyclists across the lanes to the median. The sides of the triangular island adjacent to the carriageway are approx. 20.0 m long, so that the pedestrian and cyclist crossing can be positioned at a point where the width of the triangular island is no less than 2.0 m.

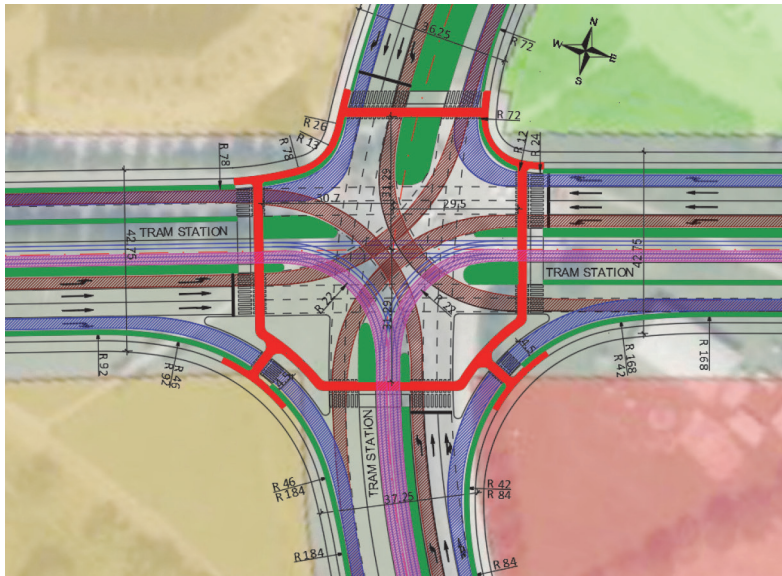


Figure 6 Variant 2 of the intersection

The geometric design of the intersection was carried out for the design vehicle, a three-axle articulated bus 18.15 metres long and tram TMK 2200 32.0 metres long. All swept paths were drawn in Autodesk Vehicle Tracking software for all directions of movement. The geometric design of the island tips on the median, the triangular islands on the bypass and the outer edges of the carriageway connecting two streets was determined according to the swept paths and with the addition of a lateral safety clearance of 25 to 50 cm. The analysis showed that the carriageway edges for right-turners in variant 1 (Fig. 5) should be designed in the form of three centred arcs (to save the space) with the ratio $R1:R2:R3 = 2:1:6$ with a radius $R2$ of 12.0 to 13.0 m. In variant 2 (Fig. 6), the carriageway edges for right-turners should be designed in the form of three centred arcs with the ratio $R1: R2: R3 = 2:1:4$, with a radius of 42 to 46 m. The width of the lane for right-turners at the triangular island is 4.5 m. The safety distance between vehicles turning left is 2.0 m.

6 Conclusions

In this article, the possibilities of geometric reconstruction of the intersection in the city of Zagreb within the given corridor on the streets Grad Vukovar and Grad Gospić were analysed. Main goal was to show what the standard design for urban intersections should look like. As a solution, two variants of a four-legged intersection with light rail in the median were presented. The newly designed intersection provides a satisfactory safe and undisturbed flow of vehicle, pedestrian, and bicycle traffic. Such solutions represent an opportunity to standardise the geometric design of intersections in the city of Zagreb and in the area of the intersection and to provide additional areas for triangular islands in the area of the intersection with the draft spatial plan. The construction of triangular islands not only increases safety, but also shortens the journey time for pedestrians and cyclists, especially in areas where there are tram or bus stops, as pedestrians and cyclists spend less time on the carriageway. The results of the study indicate that a well-designed intersection is the basis for a high quality of service and should be approached comprehensively, considering all stakeholders and the limited space available.

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